University of Memphis

University of Memphis Digital Commons

Electronic Theses and Dissertations

4-19-2011

Time Motion Analysis of Women's Collegiate Indoor Volleyball

Katie Roseanne Wells

Follow this and additional works at: https://digitalcommons.memphis.edu/etd

Recommended Citation

Wells, Katie Roseanne, "Time Motion Analysis of Women's Collegiate Indoor Volleyball" (2011). *Electronic Theses and Dissertations*. 215.
https://digitalcommons.memphis.edu/etd/215

This Thesis is brought to you for free and open access by University of Memphis Digital Commons. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of University of Memphis Digital Commons. For more information, please contact khggerty@memphis.edu.

To the University Council:

The Thesis Committee for Katie Roseanne Wells certifies that this is the final approved version of the following electronic thesis: "Time Motion Analysis of Women's Collegiate Indoor Volleyball."

Brian K. Schilling, Ph.D.
Major Professor

We have read this thesis and recommend its acceptance:

Lawrence W. Weiss, EdD.

Yuhua Li, Ph.D.

Accepted for the Graduate Council:

Karen D. Weddle-West, Ph.D.
Vice Provost for Graduate Programs

TIME MOTION ANALYSIS OF WOMEN'S COLLEGIATE INDOOR VOLLEYBALL

by

Katie Roseanne Wells

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

Major: Health and Sport Science

The University of Memphis

May 2011

Acknowledgements

The primary researcher would like to thank the thesis committee: Dr. Brian Schilling, committee chair, Dr. Lawrence Weiss and Dr. Yuhua Li, committee members.

Abstract

Wells, Katie Roseanne. M.S. The University of Memphis. May 2011. Time Motion Analysis of Women's Collegiate Indoor Volleyball. Major Professor: Brian Schilling Ph.D.

A better understanding of the demands of a sport can be determined by identifying work-to-rest ratios and frequency of high-intensity movements, but limited research has been done on indoor volleyball. Video footage of two matches for a mid-level NCAA Division I women's indoor volleyball team was analyzed using time motion analysis. Rally durations (mean of 7.6s), the rest times (18.8s), and the number of high-intensity movements (total of 1507) were recorded. The outside hitters, middle blockers, and the setter performed the greatest number of HIM per rally with means of 0.78, 0.96, and 0.98 respectively and mean HIM/s of 0.031, 0.037, and 0.038 respectively. Total work and total time were calculated, 48.3 minutes and 166.5 minutes respectively. Therefore, the ball was only in play 29.0% of total time. The overall work-to-rest ratio was 0.40:1.

Key Words: Frequency, work, rest, high-intensity

Preface

This thesis was written in article format for submission to the Journal of Strength and Conditioning Research following defense.

TABLE OF CONTENTS

List of Tables

INTRODUCTION

Volleyball is characterized by rapid and repeated application of force requiring agility and quickness on both defense and offense (35). These rapid movements include approach and block jumps, hitting or spiking the ball, and explosively reacting to the ball by passing or diving (35). Past volleyball studies have focused on injuries (primarily of the knee and shoulder) (13, 17, 27), performance measures such as jump displacement and serving accuracy (1, 7, 13-15, 22, 23, 28, 32, 34), and physiological characteristics (4, 5, 18, 20, 24, 26, 33), but the metabolic demands of indoor volleyball have not been rigorously studied.

Time motion analysis (TMA) has been described as an objective method for the quantification of movement patterns in sport situations which provides speeds, durations, distances covered, and physiological aspects of a sport within a competition setting (9, 11, 30). The temporal characteristics of activities aid in detecting the predominant energy system being used, and are a conceptual framework for the metabolic component of specific physical preparation of players (11, 12). TMA can also assist in evaluating players' performance (12). The purpose of this study is to apply TMA to volleyball.

The majority of TMA studies have investigated field sports such as rugby (8, 12, 16, 19), soccer (6, 21), or field hockey (25, 36). However, basketball (2, 3, 25), cricket (30), futsal (10), and volleyball (31) have recently been investigated. Work rates have been determined to assist coaches and strength and conditioning professionals in prescribing specific training programs (6, 8, 16, 19, 30, 36). Sport demands have been expressed as work-to-rest ratios (6, 19, 30), percentages of total time spent in activity (8, 21), or percentages of total distance covered performing purposeful movements (29). Furthermore, it was determined that only measuring total distance covered is a poor indicator of the physical stresses during an event with an intermittent nature (21), and volleyball has far less lateral than vertical (jumping) movement making distances less relevant.

Volleyball imposes high impact forces and weight-bearing load upon the axial skeleton and the neck of the femur. A player may execute up to 300 maximal jumps in a single volleyball match (4). Therefore, the large volume of maximal and submaximal jumps and landing stresses must be taken into consideration as well as the rapid, lateral movements since all of these may be categorized as a high intensity movement (31). A previous TMA performed on indoor volleyball investigated only the front row players for an elite men's team. Thus, the aim of this study is to expand on those findings by evaluating work-to-rest ratios and identifying the number and frequency of high-intensity movements of all court positions during NCAA Division I women's indoor volleyball matches.

METHODS

Experimental Approach to the Problem

This study employed a cross-sectional design- Two matches from the competitive 2007 volleyball fall season were chosen for analysis. These games were selected from games having different outcome scenarios: one a 3-0 victory and one a 3-2 victory. These games were thought to represent one of the best and one of the most evenly matched of the season which is similar to the approach used by Taylor et al (37) in which three games were chosen based on the number of fouls committed. Since volleyball has a great deal of vertical and short-duration movement, the authors used a design where the volume and frequency of high-intensity movement were also recorded in addition to work/rest ratios.

Subjects

The subjects of this study were members of a mid-level Division I women's collegiate volleyball team. All members of the team had been participating in team workouts since the middle of July. From the team of 14, only those that play substantially in the games selected were subjects of the study with a mean height of 179.3 $\pm$ 9.2cm. The protocol was approved as exempt from the university institutional review board for human subjects research.

Procedures

The video camera was set up 30 feet behind the home court end line and 10 feet above the court in the stands. This is the standard recording position for the teams scouting videos. Camera speed was standard at 60 Hz.

Each rally of the selected matches was viewed by one researcher for consistency. A rally, was operationally defined as the time from which the player serving the ball makes contact with the ball to end of play. End of play was determined by the referees whistle or an abrupt stop in play, such as a kill or block. The time of each rally and the subsequent rest period were recorded using the time on the video program and was recorded to the nearest second. The operational definition of rest in this study is the time between rallies, including timeouts.

The number of high intensity efforts completed by each player on the court was recorded in each rally according to their uniform number since players are specialized to one position no matter where they are in the serve rotation. High intensity activities were defined as jump serves, digs, jump sets, attacks/hits and blocks. Movements were counted regardless of the success of the outcome.

Statistical Analysis

Work-to-rest ratios were determined by dividing active period length by the following rest period. The frequency of high intensity activities (the aforementioned categories) was also determined over the course of both work and total play time. A t-test was used to compare values for the 3-2 victory and 3-0 victory to detect differences related to match outcome. Since playing positions were known, a one way ANOVA was run to determine if differences between positions exist. Significance level was set at $p \leq .05$. Tukey post hoc tests were performed in the case of significant main effects. Cohen's d effect sizes were calculated to compare means in terms of SD.

Results

The 3-0 match consisted of 66.2 minutes total time; 22.6 minutes of work time meaning the ball was in play 34.1% of total time (Table 1). The work time per rally ranged from 1 s (a serving ace) to 39 s with a mean of 7.61s and the range of rest between rallies was 9s to 127s with a mean of 19.6s (Table 1). The work-to-rest ratios per rally ranged from 0.05:1 to 2.1:1 with a mean work-to-rest ratio of 0.39:1 $\pm$ 0.31. A total of 516 HIM were performed with a mean of 167.3 HIM per set (Table 2); the setter and middle blocker performing the majority, 142 and 139 respectively (Table 4). The number of HIM per rally for the team ranged from 0 to 22. The mean frequency of HIM per work time was 0.41/s and 0.12/s per total time (Table 3). The players performed a mean of 49.7 rallies per set with 149 total rallies.

The 3-2 match was 100.4 minutes total time; 29.8 minutes of work time, so the ball was in play 29.7% of total time. The work performed ranged from 1s to 25s with a mean of 7.64s and the rest periods ranged from 10s to 93s with a mean of 18.1s. Therefore, the work-to-rest ratios per rally ranged from 0.01:1 to 1.91:1 with a mean of 0.42:1 $\pm$ 0.33. There were 991 HIM performed in the match; the setter performing 237 HIM and the middle blockers performing 234. The outside hitters followed performing 202 HIM in the match. The number of HIM ranged from 0 to 16 per rally. The mean frequency of HIM was 0.16/s. The players performed a mean of 47.8 rallies per set with 991 total rallies.

There was no significant difference found between the work or rest times of the two matches ($p = 0.961$ and 0.349 respectively). Work-to-rest ratios were significantly different between the matches ($p = .05$) with the mean in the 3-0 victory (0.39:1) significantly less than the 3-2 victory (0.42:1). The frequency HIM per work time and total time of the matches was also significantly different with $p<.000$. The frequency HIM per work time was 0.41 and 0.12 per total time in the 3-0 victory while the mean frequency HIM per mean work time was 0.52 and 0.17 per mean total time in the 3-2 victory. With both matches combined, the mean work time was 7.6s per rally and a mean rest time of 18.9s per rally (Table 1). The team performed a total of 1507 HIM with a mean of 185.1 HIM per set and 3.81 per rally (Table 2).

The results of the one way ANOVA for HIM by player positions demonstrated a significant interaction ($p<.000$). Tukey post hoc test for frequency HIM determined that the outside hitter (0.031), the middle blockers (0.037), and the setter (0.038) performed significantly more HIM than the right side hitter (0.012: $P=.000$ with effect sizes of 3.9, 4.9, and 6.5 respectively), defensive specialist- right back (0.004: $P=.000$ with effect sizes of 8.0, 11.6, and 13.5 respectively), defensive specialist- middle back (0.011: $P=.000$ with effect sizes of 3.5, 4.4, and 5.6 respectively), defensive specialist- left back (0.005: $P=.000$ with effect sizes of 5.7, 6.7, and 8.9 respectively), and the libero (0.015: $P=.000$ with effect size of 3.2, 4.2, and 5.5 respectively). The defensive specialist- right back ($P=.002$) and the defensive specialist- left back ($P=.003$) had significantly less HIM than the libero with an effect size of 2.5 and 1.8 respectively.

Discussion

This investigation had two purposes: to identify work-to-rest ratios and the frequency of high-intensity movements in women's collegiate volleyball using TMA, and compare these values to determine their relationship with match outcome. We hoped to provide a better understanding of the demands of the game and provide information to potentially improve the specificity of the strength and conditioning programs of these athletes (37). The definition of work-to-rest ratio is somewhat subjective depending on the varied definition of rest, with some analyses including periods of low-intensity activity at rest (9). This is especially important in volleyball since not all athletes are active during the entire work period.

We expected to find minor differences in work-to-rest ratios and in high-intensity movements between sets and matches. No significance was found between the work (P=.96) and rest (p=.35) times of both matches; however, there was significance in the work-to-rest ratios (P=.05). We conclude that the reason for significance in the work-to-rest ratios was due to the length of the 3-2 victory being much longer than the 3-0 victory. The mean rest time per rally was 19.6s for the 3-0 win and 18.1s for the 3-2 win. We hypothesize that the difference lies in the higher number of substitutions made in the 3-0 win by both teams than in the 3-2 win.

This study revealed an overall mean rally time of 7.6 seconds and an overall mean rest time of 18.9 seconds per rally with a mean HIM per rally of 3.8, which confirms the observations that there is a reliance on the ATP-PCr energy system. The longer rallies, such as the 39-second rally, could utilize the glycolytic system, but is unlikely since players are not continuously active throughout a rally. Rest time between rallies ranged from a time-out of 127 seconds to as short as 9 seconds, which appears to be ample recovery time based on the relatively short work periods.

The overall work-to-rest ratio for women's collegiate volleyball is 0.40:1, which is considerably less than rugby referees with a work-to-rest ratio of 2:1 (19). However, players spent more time in play than Australian Rules Field Umpires that were found to have a work-to-rest ratio of 1:4.5 (6). It is important, however, to train for the full range of work-to-rest, in which 2.1:1 was the maximum work-to-rest performed in one rally determined in the analysis of the two matches. An individual volleyball player may not be highly active for the entire time the ball is in play and since a goal of this investigation was to obtain data on which to base a conditioning program, indoor volleyball may be better described by using HIM per unit time (37).

A total of 1507 HIM were performed, 516 in the 3-0 win and 991 in the 3-2 win. An independent t-test found a significant (P = .34) between the total HIM performed in each match due to the greater number of rallies in the 3-2 win compared to the 3-0 win. The right side hitter, defensive specialist- right back, defensive specialist- middle back, defensive specialist- left back, and the libero all were shown to have significantly less HIM than the outside hitter, middle blocker, and setter with effect sizes ranging from 3.2 to 13.5. The middle blockers have a large number of HIM due to the nature of the position, which are mostly block jumps. Middle blockers, also, need to be very agile performing lateral movements to perform block assists with the right side and outside hitters. The defensive specialist- right back also had significantly less HIM than the libero with an effect size of 2.5. The setter significantly more HIM than all other positions except the outside hitter and middle blocker while the libero performed significantly less HIM than the outside hitter, middle blocker, and setter yet performed significantly more HIM than the defensive specialist- right back and the defensive specialist- left back. The libero is a defensive specialist that, typically, plays defense for the middle blockers, can enter the game at any time, but can only serve for one player throughout a set. Many setters only jump set on occasion, but the setter in the two matches that were analyzed is unique due to the large number of jump sets. The outside hitters have a high number of HIM from attacks and they also perform a large number of digs during serve receive and on defense.

Limited TMA research has been done concerning indoor volleyball (31). Indoor volleyball players appear to primarily utilize the ATP-PCr energy system with 0.15 HIM/s based on our data. Other sports requiring short bouts of high-intensity activity such as field hockey, basketball, and American football may also benefit from similar analysis, as some players are not active the entire time the ball is in play. An individual coach may want to perform such an analysis due to the unique situations their team may encounter (run-&-gun basketball, no-huddle offenses in American football, etc.) A greater degree of specificity through training the specific energy system will improve competition by reducing fatigue, and can also reduce the risk of injury (37).

Despite the lack of the 0-3 loss with which to compare, we feel our sample size is adequate concerning work-to-rest ratios and the rate of HIM. The nature of the sport includes many rallies and HIM over the course of the game. Continued investigation is necessary to provide additional understanding of the demands of this sport and to improve the specificity of strength and conditioning programs of these athletes. Including heart rate during a match will add to our knowledge of the demands of indoor volleyball (37). We suggest additional study on other levels of indoor volleyball and comparisons of men and women's indoor volleyball.

Practical Applications

Time motion analysis reveals a reliance on the ATP-PCr energy system to perform the high-intensity demands of indoor volleyball with little glycolytic contribution. The rate of high-intensity activities is relatively low, suggesting that absolute maximal power is more important to success than high-intensity endurance. During the pre-season, training programs should be designed to fit the range of work-to-rest ratios (0.01:1 to 2.1:1), the number of team HIM per rally (ranging from 0 to 22), and should train to improve specific performances based on the player's position (37). Outside hitters perform digs as well as attacks and blocks; whereas the middle blockers perform many lateral movements to assist the outside hitters and right side hitters performing block jumps. The setters need to be trained for high-intensity endurance due to the large amount of submaximal activity (moving around the entire court to set the ball and performing a high number of defensive plays as well). These findings were based on mid-level collegiate women's indoor volleyball, so training programs should be adjusted based on the level of the player's ability.

References

1. Barnes JL, Schilling BK, Falvo MJ, Weiss LW, Creasy AK, and Fry AC. Relationship of Jumping and Agility Performance in Female Volleyball Athletes. *J STRENGTH CONDITION RES* 21: 1192-1196, 2007.

2. Ben Abdelkrim N, El Fazaa S, and El Ati J. Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br. J. Sports Med.* 41: 69-75; discussion 75, 2007.

3. Ben Abdelkrim N, Castagna C, Jabri I, Battikh T, El Fazaa S, and Ati JE. Activity profile and physiological requirements of junior elite basketball players in relation to aerobic-anaerobic fitness. *J. Strength Cond Res.* 24: 2330-2342, 2010.

4. Calbet JA, Diaz Herrera P, and Rodriguez LP. High bone mineral density in male elite professional volleyball players. *Osteoporos. Int.* 10: 468-474, 1999.

5. Chamari K, Ahmaidi S, Blum JY, Hue O, Temfemo A, Hertogh C, Mercier B, Prefaut C, and Mercier J. Venous blood lactate increase after vertical jumping in volleyball athletes. *Eur. J. Appl. Physiol.* 85: 191-194, 2001.

6. Coutts AJ, and Reaburn PRJ. Time and motion analysis of the AFL field umpire. *Journal of Science and Medicine in Sport* 3: 132(8), 2000.

7. Dalrymple K, Davis S, Dwyer G, and Moir G. Effect of Static Stretching and Dynamic Stretching on Vertical Jump Performance in Collegiate Women Volleyball Players. *J. Strength Cond Res.* 24: 149-155, 2010.

8. Deutsch MU, Kearney GA, and Rehrer NJ. Time - motion analysis of professional rugby union players during match-play. *J. Sports Sci.* 25: 461-472, 2007.

9. Dobson, BP and Keogh, WL. Methodological issues for the application of time-motion analysis research. *Strength & Conditioning Journal* 29: 48-55, 2007.

10. Dogramaci SN, Watsford ML, and Murphy AJ. Time-Motion Analysis of International and National Level Futsal. *J. Strength Cond Res.* , 2010.

11. Dogramaci SN, Watsford ML, and Murphy AJ. The Reliability and Validity of Subjective Notational Analysis in Comparison to Global Positioning System Tracking to Assess Athlete Movement Patterns. *J. Strength Cond Res.* , 2010.

12. Duthie G, Pyne D, and Hooper S. Time motion analysis of 2001 and 2002 super 12 rugby. *J. Sports Sci.* 23: 523-530, 2005.

13. Forthomme B, Croisier JL, Ciccarone G, Crielaard JM, and Cloes M. Factors correlated with volleyball spike velocity. *Am. J. Sports Med.* 33: 1513-1519, 2005.

14. Gabbett T, Georgieff B, Anderson S, Cotton B, Savovic D, and Nicholson L. Changes in skill and physical fitness following training in talent-identified volleyball players. *J. Strength Cond Res.* 20: 29-35, 2006.

15. Gabbett TJ. Do skill-based conditioning games offer a specific training stimulus for junior elite volleyball players? *J. Strength Cond Res.* 22: 509-517, 2008.

16. Hartwig TB, Naughton G, and Searl J. Motion Analyses of Adolescent Rugby Union Players: A Comparison of Training and Game Demands. *J. Strength Cond Res.* , 2010.

17. Herrington L. Knee Valgus Angle During Landing Tasks in Female Volleyball and Basketball Players. *J. Strength Cond Res.* , 2009.

18. Kasabalis A, Douda H, and Tokmakidis SP. Relationship between anaerobic power and jumping of selected male volleyball players of different ages. *Percept. Mot. Skills* 100: 607-614, 2005.

19. Kay B, and Gill ND. Physical demands of elite Rugby League referees, part two: heart rate responses and implications for training and fitness testing. *Journal of Science and Medicine in Sport* 7: 165(9), 2004.

20. Kioumourtzoglou E, Michalopoulou M, Tzetzis G, and Kourtessis T. Ability profile of the elite volleyball player. *Percept. Mot. Skills* 90: 757-770, 2000.

21. Krustrup P, Helsen W, Randers MB, Christensen JF, MacDonald C, Rebelo AN, and Bangsbo J. Activity profile and physical demands of football referees and assistant referees in international games. *J. Sports Sci.* 27: 1167-1176, 2009.

22. Lidor R, Arnon M, Hershko Y, Maayan G, and Falk B. Accuracy in a volleyball service test in rested and physical exertion conditions in elite and near-elite adolescent players. *J. Strength Cond Res.* 21: 937-942, 2007.

23. Malatesta D, Cattaneo F, Dugnani S, and Maffiuletti N. Effects of Electromyostimulation Training and Volleyball Practice on Jumping Ability. *J. Strength Cond Res.* 17: 573-579, 2003.

24. Marques M, Van Den Tillar R, Gabbett T, Reis V, and Gonzalez-Badillo J. Physical Fitness Qualities of Professional Volleyball Players: Determination of Positional Differences. *J. Strength Cond Res.* 23, 2009.

25. Matthew D, andDelextrat A. Heart rate, blood lactate concentration, and time-motion analysis of female basketball players during competition. *J. Sports Sci.* 27: 813-821, 2009.

26. Melrose DR, Spaniol FJ, Bohling ME, and Bonnette RA. Physiological and performance characteristics of adolescent club volleyball players. *J. Strength Cond Res.* 21: 481-486, 2007.

27. Osborne NJ, and Gatt IT. Management of shoulder injuries using dry needling in elite volleyball players. *Acupunct. Med.* 28: 42-45, 2010.

28. Quiroga ME, Garcia-Manso JM, Rodriguez-Ruiz D, Sarmiento S, De Saa Y, and Moreno MP. Relation between in-game role and service characteristics in Elite women's volleyball. *J. Strength Cond Res.* 24: 2316-2321, 2010.

29. Rebelo AN, Ascensao AA, Magalhaes JF, Bischoff R, Bendiksen M, and Krustrup P. Elite Futsal Refereeing: Activity Profile and Physiological Demands. *J. Strength Cond Res.* , 2010.

30. Rudkin ST, and O'Donoghue PG. Time-motion analysis of first-class cricket fielding. *J. Sci. Med. Sport* 11: 604-607, 2008.

31. Sheppard JM, Gabbett TJ, and Reeberg Stanganelli L. An analysis of playing positions in elite men's volleyball: Considerations for competition demands and physiologic characteristics. *J STRENGTH CONDITION RES* 23: 1858-1866, 2009.

32. Sheppard JM, Chapman DW, Gough C, McGuigan MR, and Newton RU. Twelve-month training-induced changes in elite international volleyball players. *J. Strength Cond Res.* 23: 2096-2101, 2009.

33. Sibley BA, and Etnier JL. Time course of attention and decision making during a volleyball set. *Res. Q. Exerc. Sport* 75: 102-106, 2004.

34. Smith DJ, Stokes S, and Kilb B. Effects of Resistance Training on Isokinetic and Volleyball Performance Measures. *Journal of Applied Sport Science Research* 1: 42-44, 1987.

35. Smith R. Movement in the Sand: Training Implications for Beach Volleyball. *J. Strength Cond.* 28: 19-21, 2006.

36. Spencer M, Lawrence S, Rechichi C, Bishop D, Dawson B, and Goodman C. Time-motion analysis of elite field hockey, with special reference to repeated-sprint activity. *J. Sports Sci.* 22: 843-850, 2004.

37. Taylor J. Basketball: applying time motion data to conditioning. *STRENGTH CONDITION J* 25: 57-64, 2003.

38. Williams C. Time Motion Analysis of Men's Professional Beach Volleyball. Masters of Science, University of Memphis, 2010.

Appendix A

Table 1: Work/rest times (s)

	Set	Total Time (s)	Total Work Time (s)	# of Rallies	Mean Work Per Rally (s)	Total Rest time (s)	# of Rest periods	Mean Rest Per Rally (s)	Work/Rest
3-0 Victory	**1**	1354	394	52	7.6	960	51	18.8	0.41
	2	1266	344	48	7.2	922	47	19.6	0.37
	3	1349	373	49	7.6	976	48	20.3	0.38
	Mean	1323	370.3	49.7	7.5	952.7	48.7	19.6	*0.39
3-2 Victory	**1**	1191	360	51	7.1	831	50	16.6	0.43
	2	1271	403	54	7.5	868	53	16.4	0.46
	3	1236	351	50	7.0	885	49	18.1	0.40
	4	1579	459	58	7.9	1120	57	19.7	0.41
	5	746	214	26	8.2	532	25	21.3	0.40
	Mean	1204.6	357.4	47.8	7.5	847.2	46.8	18.1	*0.42
Combined Mean		1263.8	363.9	47.8	7.6	900.0	47.7	18.9	0.40

*Indicates a significant (p=.05) difference in work/rest between matches.

Table 2: High-intensity movements per set and rally

	Set	Total HIM Per Set	HIM Per rally
3-0 Victory	**1**	174	3.35
	2	156	3.25
	3	186	3.80
	Mean	*172	3.46
3-2 Victory	**1**	191	3.75
	2	202	3.74
	3	206	4.12
	4	266	4.59
	5	126	4.85
	Mean	*198.2	4.15
Combined Mean		185.1	3.81
SD		18.53	0.49

*Indicates a significant (p=.034) difference in total HIM between matches.

Table 3: Frequency of high-intensity movements per total time and work time

	Total Time (s)	Work Time (s)	Total HIM	Frequency per total time	Frequency per work time
3-0 Win	3969	1111	*516	^0.13	~0.46
3-2 Win	6023	1787	*991	^0.16	~0.55
Total	9992	2898	1507	0.15	0.52
Mean	4996	1449	753.5	0.15	0.52
SD	1452.4	478.0	335.9	0.02	0.06

*Indicates a significant (p=.000) difference in total HIM. ^Indicates a significant (p=.000) difference in frequency per total time. ~Indicates a significant (p=.000) difference in frequency per work time.

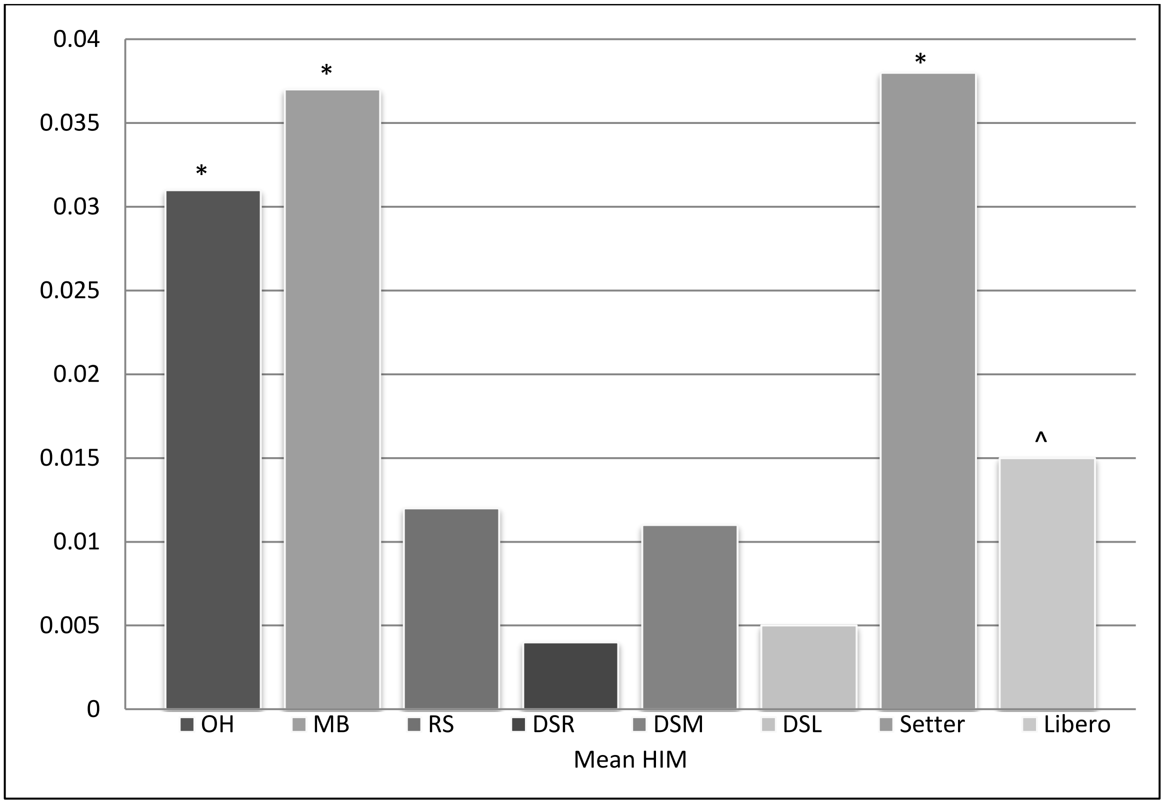
Table 4: High-intensity movements per player position

	Total HIM	HIM per rally	HIM per set	HIM per match
Outside Hitter	304	0.78	38	152
Middle Blocker	373	0.96	46.6	186.5
Right Side Hitter	110	0.28	13.8	55
Defensive Specialist (right)	46	0.12	5.8	23
Defensive Sp. (middle)	104	0.27	13	52
Defensive Sp. (left)	46	0.12	5.8	23
Setter	379	0.98	47.4	189.5
Libero	145	0.37	18.1	72.5
Mean	188.4	0.49	23.6	94.2
SD	141.2	0.36	17.7	70.6

Table 5: Frequency of high-intensity movements per unit total time

	3-0 Win: Set 1	3-0 Win: Set 2	3-0 Win: Set 3	3-0 Match Mean	3-2 Win: Set 1	3-2 Win: Set 2	3-2 Win: Set 3	3-2 Win: Set 4	3-2 Win: Set 5	3-2 Match Mean
Outside Hitter	0.027	0.024	0.026	0.026	0.032	0.033	0.034	0.034	0.035	0.034
Middle Blocker	0.033	0.032	0.039	0.035	0.039	0.037	0.035	0.046	0.032	0.039
Right Side Hitter	0.008	0.009	0.010	0.009	0.010	0.010	0.011	0.011	0.025	0.012
Defensive Specialist (right)	0.006	0.006	0.007	0.007	0	0.004	0.006	0.003	0.003	0.003
Defensive Sp. (mid)	0.001	0.003	0.007	0.004	0.019	0.013	0.015	0.012	0.019	0.015
Defensive Sp. (left)	0.006	0.005	0.003	0.005	0.015	0.006	0.002	0	0	0.005
Setter	0.036	0.036	0.036	0.036	0.036	0.041	0.042	0.040	0.036	0.039
Libero	0.011	0.008	0.011	0.010	0.008	0.015	0.022	0.022	0.019	0.017

Figure 1: Mean frequency high-intensity movements per player position



OH=outside hitter; MB=middle blocker; RS=right side hitter; DSR=defensive specialist- right back; DSM=defensive specialist- middle back; defensive specialist- left back
*Indicates significantly (p=.000) more HIM compared to each of the other positions. ^Indicates that the libero performed significantly more HIM than DS-right (p=.002) and DS- left (p=.003).

Appendix B

EXTENDED LITERATURE REVIEW

Definition of Time Motion Analysis

Managing the physical and physiological status of elite athletes relies on detailed knowledge regarding the demands of performance (7). Time motion analysis (TMA) has been described as an objective method for the quantification of movement patterns in sport situations which provides speeds, durations, distances covered, and other physiological aspects of a sport within a competition setting (14, 16, 41). The use of TMA has focused on temporal characteristics of activities, aids in detecting the predominant energy system being used, and is a conceptual framework for the metabolic component of specific physical preparation of players (16, 18). TMA is thought to increase the specificity of strength and conditioning programs by determining the physical demands of the sport (18). Knowing the distance covered or the range of speeds attained can help in planning training sessions, developing suitable training programs, and can be used to evaluate players' performance (8).

Two methods have typically been used to perform TMA; video-based analysis and analysis via Global Positioning System (GPS). Video-based analysis is the most commonly used method (14). The use of one to four cameras is the typical approach where each camera is focused on a single player or position (14). Deutsch et al. recommends a 5-m radius around the player for an optimal balance between maximizing the proportion of the field of view and having an adequately-sized frame of reference (12). This allows the analyst to have a closer view of the player's movement, which may increase the accuracy of their evaluation of locomotor movements. However, this process is relatively labor-intensive and requires a greater amount of time and skill to video-tape (16).

The second video-based method utilizes one or two cameras placed at the halfway mark with each camera focused on the entire playing area or one-half of the field or court and a small overlap to ensure complete coverage (12). The recommendation is to have the cameras set up at an elevation between 3 to 20-m and 5 to 10-m from the sidelines for field sports (14, 47). This method allows the analyst to view the movements of all the players during the entire competition and allows for all players to be analyzed, which is less time-consuming but also makes it more difficult to accurately identify the locomotor movements (47).

GPS is the second technique of TMA, which allows for accurate measurements of horizontal movements, allows multiple players to be monitored at the same time, and is time-effective during analysis (2). However, information regarding reliability and validity of GPS units are sparse, so the interpretation of time-motion results is of concern because GPS units are shown to have poor reliability at high-intensity running (2, 8, 17). It uses approximately three satellites to determine position and calculates speed and distance traveled. There are two units that attach to each player; one around the player's upper back and the other is sewn into a neoprene sleeveless shirt (39). Several disadvantages exist for GPS usage compared to video-based TMA. An example is that GPS currently cannot be used indoors or within heavily developed areas due to satellite interference from the large buildings (14). Another disadvantage is that the player must wear a unit, which limits its use in sports with physical contact (14, 39). Since GPS is limited to horizontal displacement, any sport involving vertical displacement, like volleyball, cannot use this method for TMA.

Volleyball

William G. Morgan invented volleyball in 1895 where he was the Director of Physical Education at the Young Men's Christian Association (YMCA). Morgan took characteristics from tennis, handball, basketball, and baseball to derive the game of Mintonette (renamed volleyball since the object of the game is to "volley" the ball back and forth across a net). Mintonette was designed because basketball was deemed too violent and intense for the older men. The first rules required a net at a height of 6 feet 6 inches and a 25 by 50-foot court, each team could have as many players as they wanted, and there were no limits on the number of contacts before the ball being sent over the net (48). The first official game of volleyball was played in 1896 at Springfield College. Indoor volleyball quickly became one of the most popular sports by 1907; and by 1916, volleyball spread to Brazil, South America, and the Philippines (48). The Olympic committee adopted indoor volleyball in 1964 and in 1981 became an NCAA (National Collegiate Athletic Association) sport (48). Several organizations, like USA Volleyball and FIVB, have been formed due to the popularity of the sport for the purpose of developing and approving official rules (19).

Today's rules are somewhat different, but the game has still kept distinctive characteristics. A few changes are that the court has been extended to 29 feet 6 inches by 59 feet with a net height of 7 feet 4 ⅛ inches for women and 7 feet 11⅝ inches for men, a team is limited to having six players on the court at any given time, and each side is limited to three contacts before the ball must be sent over the net (19). Volleyball is characterized by rapid and repeated application of force requiring agility and quickness to defend an opponent's attack, transitioning from defense to offense (46). These rapid movements include approach and block jumps, hitting or spiking the ball, and explosively reacting to the ball by passing or diving (46).

Previous Volleyball Studies: Injuries

Past volleyball studies have focused on injuries (predominantly of the knee and shoulder), performance measures, and physiological characteristics (25, 45). Fifteen female collegiate basketball players and fifteen female collegiate volleyball players performed three test trials of a bilateral drop jump and three test trials of a unilateral step landing task (25). A frontal projection angle of knee valgus alignment was measured during both tasks and a digital camera filmed the landing target perpendicular to the frontal plane. The average knee valgus angle value from the three trials was used for analysis (25). The results of this study indicate that knee valgus angles vary significantly between basketball and volleyball players. Basketball players showed superior control of knee valgus during the unilateral task compared to the volleyball players (25). This may be due to a limited sports-specific unilateral balance tasks within the game of volleyball; whereas basketball players pivot on and around a stance leg (25). Those involved in conditioning these athletes should consider improving bilateral landing mechanics in basketball players and improve unilateral landing technique in volleyball players (25).

Shoulder injuries, primarily overuse injuries, are also prevalent in volleyball players due to the repetitive nature of the game and possibly to muscle imbalance (20, 36). Four female volleyball players from Great Britain National Women's Volleyball Squad, all complaining of anterolateral shoulder pain and were right arm dominant, participated in a study involving the management of shoulder injuries. The high volume of hitting activities (as well as serving activities) combines with poor mechanics to produce the overuse injuries (36). Dry needling is a technique that involves the direct insertion of acupuncture needles (3-4 inches in length) in which the mechanical stretch by the needle stimulates a spinal reflex causing a contraction of the fibers. The local stretch disentangles myosin from actin allowing it to resume its resting length (36). This study supports the use of dry needling for short-term pain relief and improved active ROM (36).

Previous Volleyball Studies: Performance Measures

Jumping performance measures and isometric leg extensor actions were evaluated in twenty-nine female collegiate athletes to determine if they would be good predictors of agility (3). Researchers determined that NCAA Division I volleyball players had significantly higher countermovement jump heights than NCAA Division III volleyball athletes, which accounted for 34% of the variance in the time from toe-off to heel-down (3). These results indicate that countermovement jump height can predict agility test time; however, since performances on other variables were similar those tests may not be good predictors of competitive performance level for collegiate volleyball athletes (3). Given that isometric leg extensor action peak force was found to be reliable, but there was no significant relationship. This is not surprising in view of the fact that it is not a dynamic movement and the countermovement jump is the most common performed in sports (3). Therefore, athletes with greater countermovement jump height are more likely to have better agility performance (3).

Malatesta et al. hypothesized that jump performance could be improved with the additional of electromyostimulation (EMS) to a preseason training program. Twelve Italian male volleyball players underwent a 40-day experimental period (three sessions per week) where the subjects partook in EMS for thirty days lasting approximately 12 minutes during their schedule practice time. No plyometrics or leg muscle training was done during this period. The final ten days were similar to the thirty-day sessions only without the EMS training. Vertical jump testing was held pre-training, post-training, and ten days after the post-training test. Subjects performed squat jumps (SJ), a countermovement jump (CMJ), and 15-s of consecutive CMJs on a switch mat that measured flight time with the best of three trials being recorded. The results of this study indicate that EMS training significantly improved the 15-s of consecutive CMJs, but did not increase the single (SJ and CMJ) jumps (31).

The ability to produce maximum ball velocity is a determining element in the effectiveness of a spike in volleyball. Nineteen male Belgian volleyball players underwent goniometric measurements of the dominant and non-dominant shoulder motion in internal and external rotation. The subjects, subsequently, performed six spikes on a resistance platform connected to a digital timer. Researchers evaluated the velocity of the six trials using a radar gun followed by an isokinetic assessment of the dominant shoulder and elbow in the supine position on a dynamometer. Results indicate that the peak torque of the internal rotators showed a relationship with ball velocity performance, particularly at the lowest isokinetic speed, which suggests that strengthening the internal rotators could increase ball velocity (20).

Isokinetic resistance training was performed three times a week for the first three weeks and twice a week for the next three weeks by ten members of the University of Calgary Women's Volleyball Team. A control group consisted of five female volleyball players. Maximum spike and block jump heights were taken on a wall target graduated in centimeters and the best of three jumps was recorded. Isokinetic measures of peak torque in the knee extension and shoulder flexion by both right and left limbs at 30 and 80 degrees per second using a Cybex II Isokinetic Dynamometer and was performed maximally three times. In order to induce a training effect, the athlete's ability to exercise at maximal or near maximal intensity at all speed setting is important. The control group showed no significant improvement in any measures. Significant improvements in the block jump occurred after only three weeks of training, but it may be due to improvement in technique. The upper body exercises in the training program did not produce significant increases when compared with the control group. The use of slow contraction speeds should be limited to the initial strength-building phase of the training program since jumping requires speed as well as strength (45).

Twenty-six talent-identified junior volleyball players underwent accuracy and technique assessments of spiking, passing, setting, and serving skills before and after eight weeks of skill-based training. Training induced significant improvements in spiking, setting, and passing accuracy while there was a trend for serving accuracy. However, the training had little effect on body mass, skinfold measurements, lower-body muscular power, or VO_2max. These findings indicate that skill-based training should be supplemented with appropriate energy system training along with strength and power training; however it is unclear whether these improvements would have transferred into game situations (21). In a later study, Gabbett evaluated twenty-five junior volleyball players before and after a twelve-week training program using skill-based conditioning games where players underwent accuracy and technique assessments similar to those in the previous study. Improvements were evident in physical fitness with skill-based conditioning games, although instructional training resulted in greater improvements in technical skill. Skill-based conditioning games showed similar physiological demands to competition and are associated with improvements in vertical jump, agility, and VO_2max in junior volleyball players (22).

Another service accuracy study compared twenty-six adolescent male subjects (fifteen from team A and 11 on team B) in a rested state and after physical exertion since high fatigue has been shown to impair performance requiring strength, endurance, and rapid movements. Designated areas were given a point value (1, 3, 5, or 7) based on difficulty. Both teams performed similarly on the service test under both conditions. These results indicate that performance was not hindered under physical exertion; however, the test needs to be administered to more novice players and to more advanced players to verify the results. Secondly, all players preferred to aim at the 7-point areas, but they were only 54% successful. Lastly, this service test is easy to administer and can be used easily by coaches to assess their players' performance (30).

Serving affects the opposing team's ability to implement a complex offense and can end up in immediate scoring. Quiroga et al. aimed to determine whether playing position is significantly related to the characteristics of their service (type, speed, service area, and effectiveness). Eight games consisted of 1,300 services delivered with fifty-two of the fifty-eight subjects taking part in international games. Results showed that 48.6% of the serves were overhead float serves that were preferred by outside players, which is not the case in men's volleyball. Next was jump spin power serves (23.9%) primarily used by outside and opposite players. Third, was the jump float serve (17%) used mostly by middle players. The highest number of points was scored through the jump spin power serve, but it also recorded the highest number of errors. There was no relation between the set score and the type of serve or its trajectory, but there was a significant relationship between the players' position and the effectiveness of the serve. Elite women's volleyball is progressing toward the types and characteristics of services seen in men's volleyball. Therefore, training should include a wide variety of services and possibly including male players. These results may be used to optimize training that would optimize the delivery of the different types of serves (38).

Twenty elite male volleyball players from the same national team were taken through vertical jump testing before and after a twelve-month strength and power training program. Subjects performed a CMVJ as well as a spike vertical jump (includes an approach) at body mass and body mass plus 50% using a vaned jump and reach apparatus while jumping from a force plate with a position transducer connected to the weight at their shoulder. Researchers compared these results to a pilot study they conducted earlier on the relationship between depth jump and CMVJ. The results indicate the depth-jump ability is highly associated with CMVJ and spike jump and showed that the stretch-shortening cycle performance is important to improving jump performance. Improvements made in this study did not reach significance, but are of clinical importance since any amount of additional jump height and power will result in better performance. A limitation of this study is that the researchers do not divulge the details of the training program. Possible changes to the training program could, potentially, result in obtaining greater increases in jumping performance (43).

Dalrymple et al. investigated the effect of static and dynamic stretching on vertical jump performance in collegiate women volleyball players. Twelve NCAA Division II female players were randomly assigned to one of three groups (static stretching, dynamic stretching, or no stretching) for the first session, and then performed the other protocols in the following sessions so that all subjects performed all of the protocols. During three testing sessions the subjects performed a low intensity jog for 5 minutes, performed their group’s protocol, and then performed a series of 5 CMJ on a force platform with each jump separated by 1 minute of passive recovery. Results indicate that peak jump height was not significantly different after both the static stretching and the dynamic stretching protocols (11).

Previous Volleyball Studies: Physiological Characteristics

Due to the explosive movements of volleyball, active phases last an average of 7 seconds, so anaerobic metabolism depends on 95% from ATP-PCr and 5% from glycolysis.

Anaerobic power is commonly measured using the Wingate Anaerobic Test, but this test may not be appropriate for athletes. Therefore, vertical jump tests may be parameters that are better measured in volleyball players and they can be done in the field rather than in a laboratory setting. Thus, Kasabalis et al. evaluated the correlation between anaerobic power and vertical jump performance in 109 male subjects of various ages. Results indicate that a vertical jump test may be sufficient to provide valid information to volleyball coaches concerning the anaerobic power of their athletes with a high correlation between peak power and vertical jump (26).

Adolescent girls from a competitive volleyball club were evaluated to determine their physical and performance characteristics by undergoing a battery of tests and measurements. Measurements included body composition using skinfold calipers, girths (neck, shoulder, waist, abdomen, hip, mid-thigh, calf, arm, and forearm), muscular strength using a hand grip and leg dynamometer, power was determined by a vertical jump test using a Vertec apparatus and a standing broad jump, speed, agility assessed using the T-test and shuttle run, muscular endurance using a 1-minute sit-up protocol, balance utilizing the stork stand protocol, flexibility using a sit-an-reach box and shoulder rotation, and serving and spiking velocity using a radar gun measured immediately after contact with the player's hand (34).

The information gathered from this study could aid coaches in identifying physical and performance data specific to an age group for evaluation and development purposes. As expected, height and weight increased with age. Weight showed a strong correlation to hand-grip strength and a moderate correlation to isometric leg strength; whereas lean body mass had slightly strong correlations to strength and power movements and showed a moderate correlation with serving velocity. Therefore, lean body mass appears to be a leading factor in higher performance. Serving and spiking velocities are important to an effective offense with higher velocities closely correlated to age and moderately correlated with experience; however, spiking velocity is less dependent upon age and experience than serving. Thus, age, experience, lean body mass, strength, and balance are key physical and performance characteristics of adolescent female volleyball players (34).

Volleyball performance is based on cognitive, motor, and perceptual abilities. Thirty male subjects from the Greek National team (n=12) and from the Department of Physical Education (n=18) underwent testing in the three different areas. A group of twenty national coaches met and selected abilities which they thought were most important to the elite volleyball athlete.

Three cognitive abilities the coaches thought were important are analytic ability, grouping of information, and retention of information. The Advanced Progressive Matrices Test evaluates analytic ability, “Super Lab” software was used to evaluate group visual information, and the “Psychological Testing Program” software tested the retention of information ability. Important motor abilities include rhythm, multilimb coordination, kinaesthesis, and coincidence. Rhythm was evaluated by the subject stepping on a cowtsouk plate in time with a metronome for 90 steps, multilimb coordination was evaluated by a flight simulator, coincidence was tested using the Bassin Anticipation Timer, and kinaesthesis was measured using the Kinaesthesiometer. And important perceptual abilities were identified as perceptual speed, focused attention, estimation of speed and direction of a moving object, and prediction. Perceptual speed was tested using “Super Lab” software, predict actions was evaluated using “VideoMashine” software, The Continuous Attention Test was used to assess focused attention, and a tracking task assessed the ability to estimate the speed and trajectory of a moving object using specially designed software (28).

Elite volleyball players did not show superior cognitive abilities over the physical education students, but the elite group was able to detect the cues faster than novices. There is a strong relationship between the perceptual and cognitive attributes. Predicting offensive moves was more efficient in the expert group and was able to estimate its speed and direction more efficiently than the novice group. Experts, also, were superior in judging coincidence, thereby influencing the coincidence anticipation timing with similar results on the rhythm task and in multilimb coordination. Kinaesthesis was the only motor ability in which experts were not superior to novices. This study can lead to a creating a description of abilities that expert volleyball players should possess (28).

Physical exercise promotes the accrual of bone mineral density (BMD) and high mechanical impact and weight-bearing activities seem more efficient in increasing BMD than exercise which does not involve impact loading (7). Volleyball is a sport which imposes high impact and weight-bearing load upon the axial skeleton and the neck of the femur in which a single match may involve more than 300 maximal jumps per player (7). Fifteen professional male volleyball players and fifteen non-active subjects underwent dual-energy x-ray absorptiometry to (DEXA) in order to calculate BMD. Calbet et al. found that volleyball players showed 20-27% greater BMD values in the femoral neck and 14% higher lumbar spine BMD values than the non-active subjects (7). The volleyball players also showed a 7% greater BMD values in the dominant arm than in the contralateral arm. These results indicate a high osteotropic capability for volleyball (7).

Another physiological characteristic that has been examined in volleyball is blood lactate levels in order to determine the energy system that contributes the highest energy production. It has been shown that lactic anaerobic metabolism contributes to energy production after 20 seconds of exercise and that lactate concentration increased significantly after 6 seconds of intense exercise. Chamari et al. hypothesized that lactic anaerobic pathways are activated from the very first seconds of exercise. In order to test their hypothesis, venous blood lactate was measured immediately following, after one minute, after 3 minutes, and after 5 minutes of recovery in eleven male volleyball players after vertical jumping (a single maximal jump, six jumps separated by 20 seconds of recovery, and six consecutive without recovery) (9). The researchers also investigated the role of the upper body in lactate increase in which the subjects performed the same protocol with only the movement of the arms. Results showed that venous blood lactate increase significantly after a maximal vertical jump and six consecutive jumps; however the six jumps separated by 20 seconds of recovery did not show a significant increase. Speculation may conclude that the approach may play an important role in lactate increase and that this increase may be explained by the activation of lactic anaerobic metabolism and/or the resynthesis of the phosphocreatine that was used in brief exercise (9).

Decision-making is an important and difficult task during sport skill performance. The primary task for twenty intermediate-level volleyball players (12 women and 8 men) was a two-handed overhead volleyball set. The direction of the set was determined by the color of the ball and they were told to set the ball through a hoop placed at net height, parallel to the ground. Point values of 0, 1, 2, or 3 were given and totaled after twenty front sets, twenty back sets, and twenty choice sets. The secondary task was an auditory reaction time test where the subject had to respond to an auditory tone played over a speaker by yelling "ball" as quickly as possible. Results indicate that attentional demand was higher on the choice sets, which suggests that choosing the direction of the set affected the attention during the first half of the ball's flight. The findings of this study showed that reaction times were faster at two time periods (PP2 andPP3) which indicate lowered attentional demand at these time points. The addition of decision-making requirements negatively affected setting accuracy. These results could have implications in other sports that require strategic decision-making (44).

Marques et al. investigated the anthropometric and strength characteristics of thirty-five professional male volleyball athletes and to determine if differences exist according to playing position. The subjects underwent the following measurements and tests: height, and body mass, countermovement jump height (CMVJ) using a trigonometric carpet, an overhead medicine ball throw using a 3-kg medicine ball, and maximal dynamic strength using a 4-repetition bench press and a 4-repetition parallel squat. Results indicate that there are significant anthropometric characteristics and muscular strength differences based on playing position. Strength differences in the bench press can be attributed to the geometric scaling paradigm that states that strength is directly related to muscle cross-sectional area which increases with increasing body height. Therefore, bench press performance could be explained since middle blockers are significantly taller than the liberos and setters. However, when the differences were expressed according to relative strength the differences and the positive correlation were no longer evident. No significant relationships were found in the parallel squat or the CMVJ possibly due to the fact that all positions use the stretch-shortening cycle. Results of this study can be used by coaches to determine the type of physical profile that is needed for specific positions and to design resistance training programs to maximize strength and power development for individual athletes (32).

Previous TMA Studies focused on individual players

The majority of TMA studies have been performed on rugby, soccer, or field hockey (33, 47). However, basketball (4, 33), cricket (41), futsal (15), and volleyball (42, 49) have recently been investigated. Video-based analysis was the most common TMA method used in the studies reviewed, although the researchers used different approaches to their data collection. Most of the studies filmed individual athletes for data collection; however, some used stationary cameras to view the entire field or court. Besides the differences in filming technique, the most common variables investigated were movement patterns and work-rate.

Movement patterns were typically filmed so the focus was a single player's movement rather than the entire playing area using zoom (6, 10, 12, 14, 23, 27, 39, 41). Several studies used multiple cameras to track individual player movements. Deutsch et al. evaluated professional rugby union players and determined that forwards spent 12-13% of total match time in high intensity activities because of their involvement in rucking, mauling, and scrimmaging (12, 13, 18). However, backs spend two to three times more time in high intensity running (13). This indicates a need for specificity in training for different player positions due to the large differences in movement demands (18). Rugby, unlike other intermittent sports, has a large horizontal component to the game and time motion analysis does not have the ability to evaluate the specific demands of certain movements or combinations of movements, such as skill or decision-making (13).

A study conducted by Hartwig et al. evaluated adolescent rugby union players using three cameras during matches and GPS during practices to compare on-field training practices to game demands as well as comparing the physiological demands of different playing positions(24). The researchers determined that there were great differences between the demands of training practices and game demands. Players covered greater distances and performed more sprints during games and that the rugby training sessions did not adequately simulate the high-velocity-repeated-sprint demands of games (24). Since research has shown that training specificity is important for eliciting adaptations, the conclusions of this study are that future research needs to focus on how coaches can achieve training efficiency and specificity without increasing the volume of training sessions (24).

Krustrup et al. filmed fifteen male soccer assistant referees with two cameras; one filming a broad view of the entire field and the other zoomed in on the individual to achieve the best view of the athlete's movement patterns (29). Frequency and duration of each locomotor movement (1,053 total activities) was recorded and the researchers concluded that performance was impaired during the second half of the match resulting in a reduced ability to achieve the best view of the play (29). However, part of the variance could be explained by the differences in the tempo of the games officiated (29). Through a semiautomatic TMA system, Osgnach et al. evaluated the energy cost and metabolic power of elite soccer athletes from 56 matches of the Italian "Serie A" encompassing 399 players from twenty teams (37).

Similarly, Bloomfield et al. video-taped 55 professional football (i.e. soccer) players from the English Premier League for fifteen-minute periods on six occasions (6). The researchers performed a detailed time-motion analysis of "purposeful movements" (PM) and determined that there was a significant correlation between position and the percentage of time during PM high-intensity activity (6). Less than half the PM was performed in the forward direction (6). Referees have the responsibility to implement rules and to assure that players abide by the rules. Therefore, referees are obligated to keep up with play to be in a good position to make quality calls (40). Futsal is an indoor sport similar to soccer, however differences exist in the size of the pitch, the number of players, and in the total duration of the match, which may impose physical and physiological differences (40). Eighteen futsal referees were evaluated during nine official professional matches resulting in a change in activity every 3.5 seconds and a total distance covered of 5.89 km, in which only 0.96km was high intensity running. Combined with the high number of activity changes the data show that unconventional movement, accelerations, and decelerations are important to the activity profile of futsal referees. Therefore, futsal referees need to combine high and low intensity forward running and sideways running with prolonged intermittent exercise aerobic high-intensity training (40).

Randers et al. tracked highly trained football (i.e. soccer) players with a multiple camera semi-automatic passive analysis system (Amisco Pro™) that used eight cameras positioned at the top of the stadium and compared these results to a manual video-based time motion analysis system where the cameras were placed at midfield, 20 m high, and 30 m from the touchline and, also, to two GPS tracking systems to determine accuracy (39). "The researchers evaluated the ability of each system to track player movement and to detect changes during the game" (39). Frequency, distance covered, and time spent in movements was determined and compared by the four analysis systems. High intensity running ranged from 1.61 km (video-based analysis) to 2.65 km (semi-automatic camera system) compared to 9.51 km (video-based analysis) and 10.83 km (semi-automatic camera system) of total distance covered (39). Total distance covered, however, is a poor indicator of the physical stresses during a match (29).

Soccer is known to be a sport with a wide range of movements and intensities. The skill level, style of play, tactical strategies, playing position, and the physical capacity of the individual players on both teams all have some impact on the interval work rate of soccer matches (35). Knowing the intensity, duration, and frequency of high-intensity activities during a soccer match may create more specific training situations. Therefore, a study was conducted to quantify the duration and intensity of each work bout and the duration and intensity of each recovery bout during a soccer match (35). The researchers used StepWatch Activity Monitors™ that graphically displayed the data in a square wave to clearly define the intensity, frequency, and duration of each step taken by the players. Using a square wave may give more precise information about the success of a specific training program, especially in the later portions of a match, and could be implemented using instantaneous velocity data from video-based digitizing systems (35).

TMA Studies filming entire playing area

Studies that filmed the entire playing area focused on gross movement patterns and distance covered typically had multiple stationary cameras that were synchronized. One study concluded that field hockey players spent 95% of total time in low intensity activity and active rest, which is less than the values previously reported (47). The differences are likely to be due to variations in the classifications of the locomotor movements (47). Basketball players changed activity every 2.82 s relative to playing time and covered ~7,558 m during the course of a game accounting for approximately 652 movements per game (5). These numbers show the need for improving aerobic and anaerobic power during practice sessions, however the small sample size is a limitation of this study (33).

Sheppard et al. investigated elite men's volleyball players to determine the demands of the front row (outsides, middles, and setters). Eight matches from the 2004 Olympic Games and eight international matches from a variety of teams were analyzed for all major activities performed. The study also included assessed vertical jump height (countermovement vertical jump and a spike jump with an approach) and anthropometric measures in elite male volleyball athletes from Argentina, Australia, Canada, and Brazil. TMA analysis revealed that middles (who are, generally, larger and heavier players) performed more attack and block jumps than the other positions. Therefore, the larger volume of jumps and landing stresses must be taken into consideration as well as the rapid, lateral movements in assisting the outside blockers. Setters had a relatively high submaximal jumping demand and outsides when jump setting and a modest jumping demand when assisting the outside blocker while outsides had greater relative jump ability on the spike jump test. The setters and middles on the winning teams had a greater blocking demand than the losing teams and the setters also had a high number of defensive dives. TMA and physiological characteristics evaluation revealed important differences in playing demand of different positions (42).

Work rates were determined in several studies to provide detailed demands of the sporting event to assist coaches and strength and conditioning professionals in prescribing specific training programs. The work rates are expressed as work-to-rest ratios, percentages of total time, or percentages of total distance covered. The study performed by Kay et al. concluded that rugby referees had a work-to-rest ratio of 2:1, which shows that sufficient rest occurs throughout the match (27). Fielding positions in cricket are perceived as undemanding, which is supported by Rudkin et al. that determined a work-to-rest ratio of 1:83.9 (41). Forwards in rugby union spent significantly more total time in high intensity work than backs and front row forwards were involved in roughly 25% more rucks and mauls than back row forwards (41). Work to rest ratios determined that Australian Rules Field Umpires spent a majority of the time in submaximal activity with a ratio of 1:4.5, which led the investigators to conclude that the change from a two-umpire system to a three-umpire system has reduced the physical demands (10). Likewise, Veale et al. concluded that low intensity activity was the predominant activity in Australian Rules Football players, so the aerobic system is heavily relied upon (50).

One investigation used heart rate monitors and blood lactate concentrations in addition to analyzing movement patterns to obtain a more detailed analysis of the physical demands of assistant soccer referees (29). The researchers used two camcorders to film the games. The results indicate that the movement patterns are characterized by long periods of low activity interspersed with short periods of intense exercise, heart rate was over 80% of the individual’s maximum heart rate for 31% of total time, and that blood lactate levels were approximately the same during the first and second halves (29). Andersson et al. analyzed video footage and heart rates of seventeen elite female soccer players to compare exercise intensity and fatigue during 54 competitive games (1). The game times were divided into smaller periods lasting fifteen minutes. Results indicate that the number of game activities and the mean duration of the games were similar, including the number of high intensity activity (1). However, more high intensity running is performed in the first four 15-minutes during international games as opposed to domestic games, but the difference was due to more frequent activity, not longer duration.

Furthermore, less high intensity running took place in the past thirty minutes in the international compared to the domestic games, indicating that the players experienced a higher degree of fatigue in the international games. A peak heart rate was found to be 187 $\pm$ 2 bpm in international games and 185 $\pm$ 2 bpm during domestic games, although there were large individual differences in fatigue development (1). The conclusions from this study suggest that female soccer players should aim to implement more high intensity aerobic training and speed-endurance training to meet the physical challenges of international play (1). Using a similar protocol, Dogramaci et al. evaluated the physiological demands of futsal, a five-a-side indoor soccer sport that is growing rapidly across the world (15). Due to the unlimited substitutions, futsal has a high-intensity energy demand and is fast-paced. The event recorder program used in this study revealed a reliance on recovery and that a superior aerobic capacity should be a priority during training, which may delay the onset of fatigue (15).

Conclusion

The methods in these studies vary widely in their approach to data collection. However, TMA has been shown to be useful in determining the physical demands of a sport and prescribing a specific strength and conditioning program to enhance performance. More research is needed in indoor volleyball among all playing positions and within the different levels of competition to add to the literature.

References

1. Andersson HA, Randers MB, Heiner-Moller A, Krustrup P, and Mohr M. Elite female soccer players perform more high-intensity running when playing in international games compared with domestic league games. *J. Strength Cond Res.* 24: 912-919, 2010.

2. Aughey RJ, and Falloon C. Real-time versus post-game GPS data in team sports. *J. Sci. Med. Sport* 13: 348-349, 2010.

3. Barnes JL, Schilling BK, Falvo MJ, Weiss LW, Creasy AK, and Fry AC. Relationship of Jumping and Agility Performance in Female Volleyball Athletes. *J STRENGTH CONDITION RES* 21: 1192-1196, 2007.

4. Ben Abdelkrim N, El Fazaa S, and El Ati J. Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br. J. Sports Med.* 41: 69-75; discussion 75, 2007.

5. Ben Abdelkrim N, Castagna C, Jabri I, Battikh T, El Fazaa S, and Ati JE. Activity profile and physiological requirements of junior elite basketball players in relation to aerobic-anaerobic fitness. *J. Strength Cond Res.* 24: 2330-2342, 2010.

6. Bloomfield J, Polman R, and O'Donoghue PG. Physical demands of different positions in FA Premier League soccer. *Journal of Sports Science and Medicine* 6: 63-75, 2007.

7. Calbet JA, Diaz Herrera P, and Rodriguez LP. High bone mineral density in male elite professional volleyball players. *Osteoporos. Int.* 10: 468-474, 1999.

8. Castellano J, and Casamichana D. Heart rate and motion analysis by GPS in beach soccer. *Journal of Sports Science and Medicine* 9: 98-103, 2010.

9. Chamari K, Ahmaidi S, Blum JY, Hue O, Temfemo A, Hertogh C, Mercier B, Prefaut C, and Mercier J. Venous blood lactate increase after vertical jumping in volleyball athletes. *Eur. J. Appl. Physiol.* 85: 191-194, 2001.

10. Coutts AJ, and Reaburn PRJ. Time and motion analysis of the AFL field umpire. *Journal of Science and Medicine in Sport* 3: 132(8), 2000.

11. Dalrymple K, Davis S, Dwyer G, and Moir G. Effect of Static Stretching and Dynamic Stretching on Vertical Jump Performance in Collegiate Women Volleyball Players. *J. Strength Cond Res.* 24: 149-155, 2010.

12. Deutsch MU, Maw GJ, Jenkins D, and Reaburn P. Heart rate, blood lactate and kinematic data of elite colts (under-19) rugby union players during competition. *J. Sports Sci.* 16: 561-570, 1998.

13. Deutsch MU, Kearney GA, and Rehrer NJ. Time - motion analysis of professional rugby union players during match-play. *J. Sports Sci.* 25: 461-472, 2007.

14. Dobson, BP and Keogh, WL. Methodological issues for the application of time-motion analysis research. *Strength & Conditioning Journal* 29: 48-55, 2007.

15. Dogramaci SN, Watsford ML, and Murphy AJ. Time-Motion Analysis of International and National Level Futsal. *J. Strength Cond Res.* , 2010.

16. Dogramaci SN, Watsford ML, and Murphy AJ. The Reliability and Validity of Subjective Notational Analysis in Comparison to Global Positioning System Tracking to Assess Athlete Movement Patterns. *J. Strength Cond Res.* , 2010.

17. Duffield R, Reid M, Baker J, and Spratford W. Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. *J. Sci. Med. Sport* 13: 523-525, 2010.

18. Duthie G, Pyne D, and Hooper S. Time motion analysis of 2001 and 2002 super 12 rugby. *J. Sports Sci.* 23: 523-530, 2005.

19. FIVB. Federation Internationale de Volleyball. www.fivb.org. 2010.

20. Forthomme B, Croisier JL, Ciccarone G, Crielaard JM, and Cloes M. Factors correlated with volleyball spike velocity. *Am. J. Sports Med.* 33: 1513-1519, 2005.

21. Gabbett T, Georgieff B, Anderson S, Cotton B, Savovic D, and Nicholson L. Changes in skill and physical fitness following training in talent-identified volleyball players. *J. Strength Cond Res.* 20: 29-35, 2006.

22. Gabbett TJ. Do skill-based conditioning games offer a specific training stimulus for junior elite volleyball players? *J. Strength Cond Res.* 22: 509-517, 2008.

23. Gabbett TJ, and Mulvey MJ. Time-motion analysis of small-sided training games and competition in elite women soccer players. *J. Strength Cond Res.* 22: 543-552, 2008.

24. Hartwig TB, Naughton G, and Searl J. Motion Analyses of Adolescent Rugby Union Players: A Comparison of Training and Game Demands. *J. Strength Cond Res.* , 2010.

25. Herrington L. Knee Valgus Angle During Landing Tasks in Female Volleyball and Basketball Players. *J. Strength Cond Res.* , 2009.

26. Kasabalis A, Douda H, and Tokmakidis SP. Relationship between anaerobic power and jumping of selected male volleyball players of different ages. *Percept. Mot. Skills* 100: 607-614, 2005.

27. Kay B, and Gill ND. Physical demands of elite Rugby League referees, part two: heart rate responses and implications for training and fitness testing. *Journal of Science and Medicine in Sport* 7: 165(9), 2004.

28. Kioumourtzoglou E, Michalopoulou M, Tzetzis G, and Kourtessis T. Ability profile of the elite volleyball player. *Percept. Mot. Skills* 90: 757-770, 2000.

29. Krustrup P, Helsen W, Randers MB, Christensen JF, MacDonald C, Rebelo AN, and Bangsbo J. Activity profile and physical demands of football referees and assistant referees in international games. *J. Sports Sci.* 27: 1167-1176, 2009.

30. Lidor R, Arnon M, Hershko Y, Maayan G, and Falk B. Accuracy in a volleyball service test in rested and physical exertion conditions in elite and near-elite adolescent players. *J. Strength Cond Res.* 21: 937-942, 2007.

31. Malatesta D, Cattaneo F, Dugnani S, and Maffiuletti N. Effects of Electromyostimulation Training and Volleyball Practice on Jumping Ability. *J. Strength Cond Res.* 17: 573-579, 2003.

32. Marques M, Van Den Tillar R, Gabbett T, Reis V, and Gonzalez-Badillo J. Physical Fitness Qualities of Professional Volleyball Players: Determination of Positional Differences. *J. Strength Cond Res.* 23, 2009.

33. Matthew D, and Delextrat A. Heart rate, blood lactate concentration, and time-motion analysis of female basketball players during competition. *J. Sports Sci.* 27: 813-821, 2009.

34. Melrose DR, Spaniol FJ, Bohling ME, and Bonnette RA. Physiological and performance characteristics of adolescent club volleyball players. *J. Strength Cond Res.* 21: 481-486, 2007.

35. Orendurff MS, Walker JD, Jovanovic M, L Tulchin K, Levy M, and Hoffmann DK. Intensity and duration of intermittent exercise and recovery during a soccer match. *J. Strength Cond Res.* 24: 2683-2692, 2010.

36. Osborne NJ, and Gatt IT. Management of shoulder injuries using dry needling in elite volleyball players. *Acupunct. Med.* 28: 42-45, 2010.

37. Osgnach C, Poser S, Bernardini R, Rinaldo R, and di Prampero PE. Energy cost and metabolic power in elite soccer: a new match analysis approach. *Med. Sci. Sports Exerc.* 42: 170-178, 2010.

38. Quiroga ME, Garcia-Manso JM, Rodriguez-Ruiz D, Sarmiento S, De Saa Y, and Moreno MP. Relation between in-game role and service characteristics in Elite women's volleyball. *J. Strength Cond Res.* 24: 2316-2321, 2010.

39. Randers MB, Mujika I, Hewitt A, Santisteban J, Bischoff R, Solano R, Zubillaga A, Peltola E, Krustrup P, and Mohr M. Application of four different football match analysis systems: a comparative study. *J. Sports Sci.* 28: 171-182, 2010.

40. Rebelo AN, Ascensao AA, Magalhaes JF, Bischoff R, Bendiksen M, and Krustrup P. Elite Futsal Refereeing: Activity Profile and Physiological Demands. *J. Strength Cond Res.* , 2010.

41. Rudkin ST, andO'Donoghue PG. Time-motion analysis of first-class cricket fielding. *J. Sci. Med. Sport* 11: 604-607, 2008.

42. Sheppard JM, Gabbett TJ, and Reeberg Stanganelli L. An analysis of playing positions in elite men's volleyball: Considerations for competition demands and physiologic characteristics. *J STRENGTH CONDITION RES* 23: 1858-1866, 2009.

43. Sheppard JM, Chapman DW, Gough C, McGuigan MR, and Newton RU. Twelve-month training-induced changes in elite international volleyball players. *J. Strength Cond Res.* 23: 2096-2101, 2009.

44. Sibley BA, and Etnier JL. Time course of attention and decision making during a volleyball set. *Res. Q. Exerc. Sport* 75: 102-106, 2004.

45. Smith DJ, Stokes S, and Kilb B. Effects of Resistance Training on Isokinetic and Volleyball Performance Measures. *Journal of Applied Sport Science Research* 1: 42-44, 1987.

46. Smith R. Movement in the Sand: Training Implications for Beach Volleyball. *J. Strength Cond.* 28: 19-21, 2006.

47. Spencer M, Lawrence S, Rechichi C, Bishop D, Dawson B, and Goodman C. Time-motion analysis of elite field hockey, with special reference to repeated-sprint activity. *J. Sports Sci.* 22: 843-850, 2004.

48. Strength and Power for Volleyball.com. Volleyball History and the Evolution of the Sport. 2010, 2007.

49. Tokuyama M, Ohashi H, Iwamoto H, Takaoka K, and Okubo M. Individuality and reproducibility in high-speed motion of volleyball spike jumps by phase-matching and averaging. *J. Biomech.* 38: 2050-2057, 2005.

50. Veale J, and Pearce A. Profile of position movement demands in elite junior Australian rules footballers. *Journal of Sports Science and Medicine* 8: 320-326, 2009.

THE UNIVERSITY OF MEMPHIS

Institutional Review Board

To:	Katie Wells Health and Sport Sciences
From:	Chair, Institutional Review Board For the Protection of Human Subjects irb@memphis.edu
Subject:	Time-Motion Analysis of NCAA Division I Women's Indoor Volleyball (021911-361)
Approval Date:	March 10, 2011

This is to notify you that the Institutional Review Board has designated the above referenced protocol as exempt from the full federal regulations. This project was reviewed in accordance with all applicable statuses and regulations as well as ethical principles.

When the project is finished or terminated, please complete the attached Notice of Completion form and send it to the Board via e-mail at irb@memphis.edu.

Approval for this protocol does not expire. However, any change to the protocol must be reviewed and approved by the board prior to implementing the change.

____

Chair or Designee, Institutional Review Board
The University of Memphis

Cc: Dr. Brian Schilling